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Chapter

Energy Use Efficiency in Irrigated and Rainfed Wheat in Pakistan

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Abstract

Wheat is an important staple food in Pakistan and is grown in both irrigated and rainfed production systems. To meet increased demand, farmers have increased the use of input energy in wheat production. The intensive use of energy has many consequences for energy security and environmental sustainability. In this chapter, we have analyzed the energy use efficiency of wheat crop grown in two different production systems using data collected from wheat farmers of Punjab province of Pakistan through face-to-face interviews. Energy input–output analysis revealed that 49,079 MJ/ha input energy is used in irrigated wheat and 31,421 MJ/ha in rainfed wheat. The main difference between both production systems is because of irrigation water. Fertilizer has the highest share in total energy consumption followed by diesel fuel. Energy consumed per kilogram of wheat produced is less in rainfed wheat compared to irrigated. Similarly, energy efficiency values of rainfed wheat are better than irrigated wheat. Results of data envelopment analysis reveal that 38% of wheat farmers in rainfed systems and 62% in the irrigated system are using energy efficiently. The substantial difference between the energy use of inefficient and efficient indicates that there's a significant potential to improve energy use efficiency in both systems.

Keywords: energy use efficiency, input–output analysis, DEA, wheat, Pakistan

1. Introduction

Population growth and increased demand for food have led humanity to look for new ways to increase food production. Energy, which is an essential input in agriculture, has been considered as a feasible option to increase food productivity and enhance food security. As a result, agriculture has become energy-intensive to meet increased food and biofuel demand [1].

After the green revolution, the introduction of high yield varieties and intensive crop management practices has increased the use of energy manifolds in both developing and developed countries [2, 3].

It is anticipated that energy input for crop production will increase further mainly due to population and economic growth, climate change, degrading quality of soils, and shortage of labor [4, 5]. On the other hand, intensive use of energy in crop production is posing many threats to agriculture sustainability, human health, and sustainability of the environment. Sometimes to get maximum returns farmers make overuse of energy inputs. This has led to increased energy used in crop production at a faster rate compared to other sectors. Escape of traditional practices in agriculture, technological advancements in Agri-machinery, and increased application rate of fertilizer is also responsible for increased use of energy in crop production. It is also ascribed to the introduction of high yielding varieties, and excessive use of biocides and chemical fertilizer. In addition to this diesel fuel consumption has also increased due to farm mechanization and pumping of underground water. Finally, scarcity of cultivable lands and irrigation water increased the human population, and the desire for improved living standards has also contributed to the intensive use of energy in agriculture. Both agriculture and the environment are dependent on each other and the efficient use of energy is a basic requirement for sustainable agriculture [6, 7]. Sustainable development of agriculture is dependent on high energy use efficiency with low energy use in crop production. Thus, increasing energy use efficiency in crop production is important for food security and environmental sustainability. Keeping in view the multiple interactions of agriculture with the environment, analysis of the consumption of energy (both operational and embodied) in the agriculture system is urgently needed to fight both environmental issues stemming from agriculture and climate change impacts on agriculture.

1.1 Environmental implications of input energy use in agriculture

Agriculture contributes 24% of global Greenhouse gases emission, and agricultural activities are considered a significant source of pollution [8, 9]. It is estimated that GHG emission from agriculture has doubled in the last 50 years, they could increase by another 30% by 2050 [10]. Increasing use of energy inputs in agriculture is associated with numerous environmental problems such as loss of biodiversity, pollution of the aquatic environment by chemical fertilizers and pesticides, and high consumption of non-renewable energy resources. Among all other energy inputs used in crop production, diesel fuel and fertilizers have the highest share of energy consumption [11, 12]. Studies have found that fertilizer and pesticides are among the most substantial secondary sources of CO2 emissions [8]. According to an intergovernmental panel on climate change [13] Direct and indirect consumption of fossil fuels for crop production leads to the emission of carbon dioxide (CO2), nitrous oxide (NO2), and methane (CH4). Climate Change resulting from greenhouse gasses is the most important environmental challenges in today's world [13]. A significant portion of these greenhouse gases is produced by agriculture. About 10–12% of all anthropogenic GHG emissions are contributed by agricultural greenhouse gasses emission [14].

The major use of commercial energy in agriculture is during the production and operation of agricultural machinery. Most of the agricultural operations like, land preparation, irrigation, fertilization, spraying, and harvesting are performed using fossil fuels. The combustion of fossil fuels in agricultural machinery releases CO2 into the atmosphere.

Excessive or over-use of fertilizers leads to loss of nutrient elements, which are main contributors to non-point source pollution from agriculture, degradation of water and soil quality, decrease in the quality of agricultural products, and increase in air emissions. Due to losses incurred by pest attacks, the use of pesticides is increasing at a higher rate. There is a 4.4% average annual growth in the use of agrochemicals worldwide [15]. This increased use of pesticides is causing air, water, and soil pollution. The increasing use of pesticides in agriculture is becoming the main environmental hazard and a major contributor to agriculture pollution. Additionally, agriculture is thought to be the major contributor of N2O by indirect and direct sources [16]. The food production system is under increasing pressure due to consistent population growth and climate change; by an increase in demand for food security while protecting the natural resources by minimizing the environmental footprints [17].

Both sustainable environment and sustainable agriculture are dependent on each other. Environmental factors have a significant contribution to agriculture; agriculture, as compared to other sectors, is more dependent on the natural environment. Agriculture is the source of food and fiber for the human being and vital for human existence; as a result, sustainable agriculture development is not just related to economic development but also human survival. Therefore, efficient use of energy is one of the conditions for sustainable agriculture [18].

1.2 Energy efficiency in agriculture

Efficient use of energy inputs helps to increase production and productivity, profitability and competitiveness of agriculture, and sustainable rural living. Higher energy use efficiency will promote sustainable agriculture by minimizing environmental problems and preventing the destruction of natural resources. The use of renewable energy sources and increase in efficiency of energy can also make a significant contribution in achieving sustainable energy development goals [19]. Currently, the world is focused to develop a production system that maintains high levels of output while minimizing the input of fossil energy and as a result, helps to reduce greenhouse gas emissions. To combat global warming, reducing emissions of greenhouse gases by minimizing the direct and indirect use of fossil fuels for crop production is a vital strategy. Energy efficiency is an essential element for achieving sustainable agricultural development. This is also important for increasing economic returns, preserving fossil fuel reserves, and sustainable agricultural production. Therefore, environmental impact assessments, energy analysis, and GHG emission assessments are important components.

2. Wheat production in Pakistan

Wheat (*Triticum aestivum* L.) is an important winter crop in Pakistan. Wheat significantly contributes to the livelihood and food security of the population in Pakistan, as well as at the global and regional levels. It meets about 1/5th of the daily calorie and protein requirement of human beings [20] and it constitutes 65% of staple food consumption in Pakistan. It contributes 1.7% to the national GDP of Pakistan and 8,7% to agriculture value addition. Wheat was cultivated on 8,25 Million hectares in 2019–2020 and the area under wheat has slightly decreased in the past five years. Over the years, wheat yield per acre has been stagnant or little change has been seen due to declined under-ground water table, soil degradation, environmental pollution, etc. delayed sowings, low germination rate, insect-pest infestation, and low crop stand has lowered the production efficiency of wheat. A further decline in wheat yield in recent years can be attributed to locust attacks. Keeping in view increasing population and government policies (increased support price from 1400/40 kg to 1650/40 kg before the wheat season in 2020), it is projected that farmer will divert their resource towards wheat to get maximum output from a limited quantity of arable land. The limited supply of labor on one hand and incentives for higher productivity on other hand will lead to increased use of energy in wheat production. In Pakistan, winter wheat is grown both irrigated and drylands. During winter availability of canal water is almost negligible and irrigated wheat is irrigated with groundwater. However, sustainability productivity of wheat crop is under threat due to over-exploitation of underground water. Moreover, a substantial amount of diesel fuel is used to pump water from underground, leading to significant consumption of diesel fuel energy in wheat production. On the other hand, water is a scarce resource and the water table is depleting rapidly in Pakistan. These both issues are posing a great threat to the environmental sustainability of Pakistan, as Pakistan is among the 10 most climate affected countries in the world. The worsening energy and water issue in Pakistan needs the urgent attention of policymakers.

2.1 Input energy use in wheat production

There's substantial use of energy in wheat production both directly and indirectly. In operations like tillage, planting, and harvesting there's a direct use of energy, while energy is indirectly used in inputs such weedicides, fertilizers, and agriculture machinery (**Figure 1**).

2.1.1 Human labor

Human labor is the most important source of the energy in agriculture, although the introduction of machines has reduced human labor in the industry in the field activities, human labor is still playing its key role. In agricultural activities, human labor is used almost at every step, from manual work on the farm,

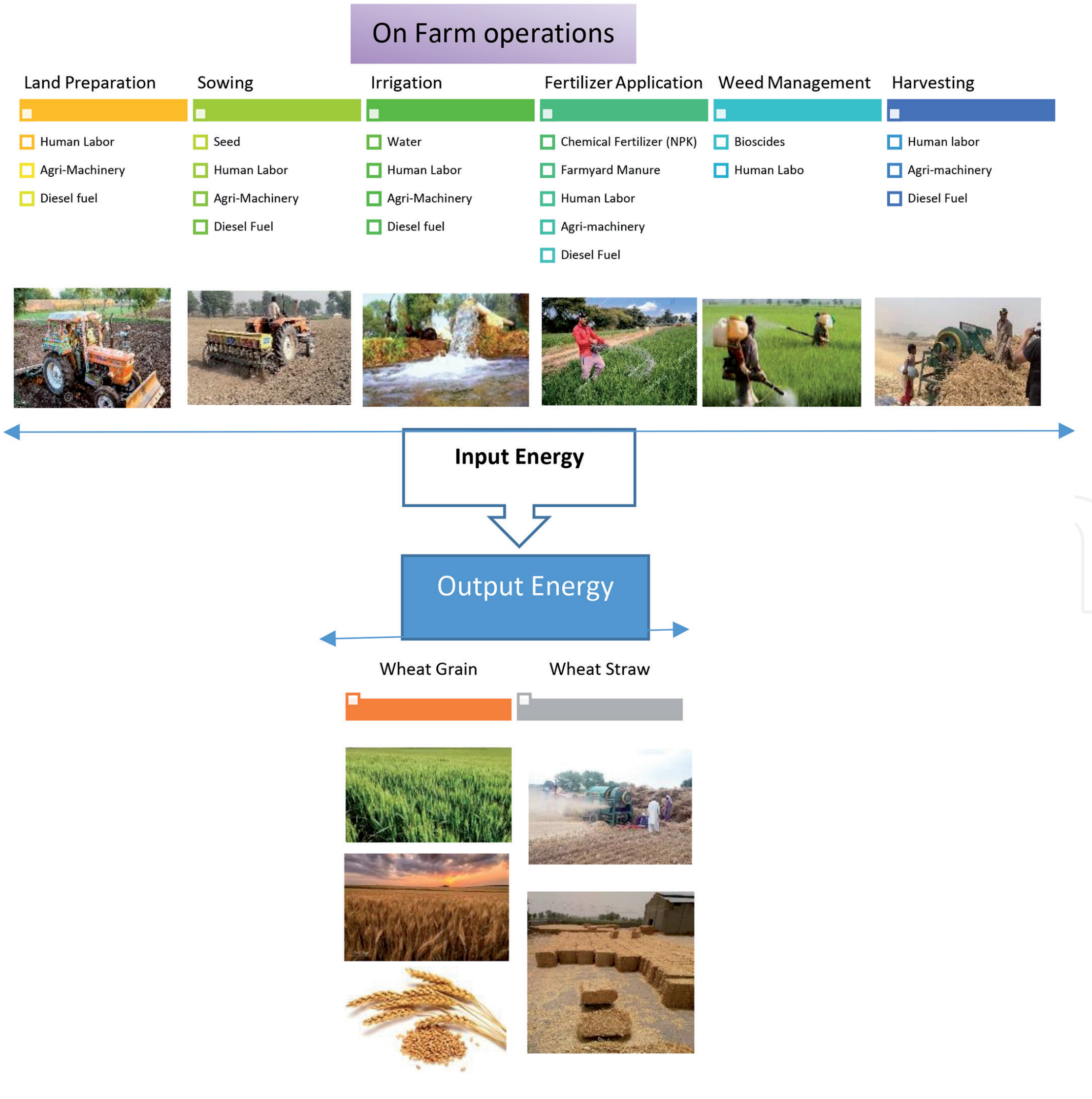

Figure 1.
System boundaries of wheat production system in Pakistan.

Inputs	Mean (S.E)	Min.	Max.	Energy equivalents
Human Labor (hours)	178.45 (6.38)	3.89	391.82	1.96
Seed (kg)	134.19 (0.86)	123.5	148.50	15.7
Diesel fuel (liter)	139.98(3.94)	29.64	397.67	56.31
Irrigation water (m^3)	8483.07 (3887)	0	612,809	1.02
Fertilizer (all)	345.15 (10.52)	0	741	
Nitrogen (kg)	177.68 (7.39)	0	617.50	66.14
Phosphate (kg)	130.7 (4.160	0	370.50	12.44
Potash (kg)	37.36 (5.36)	0	370.50	11.15
Herbicides (kg)	1.60 (0.10)	0	4.94	278
Farmyard manure (kg)	30,982.5 (2668)	0	180,000	0.3

Table 1.
Quantity of inputs used in wheat production in Pakistan and their energy equivalents.

driving agricultural machinery, maintenance, fertilizer and pesticide application, irrigation, and harvesting to management. In developing countries, human power constitutes 73% of the total energy use on farms [21]. Maybe in the future with full mechanization of farms, the use of human labor will be reduced, but some scientists believe that organic and modern agriculture needs more manual work for weeding and harvesting [22, 23]. There are different estimates for the energy output of human labor on farms. The main physical activities in wheat production are driving a tractor, manual sowing, manual fertilization and spraying, harvesting, and transportation. In this study, human labor work was calculated based on the information provided by the wheat farmers on the number of hours spent in each operation. The energy equivalent of human labor is muscle power used in the field operations of crop production. The energy equivalent of human labor is 1.96 MJ/h determined from literature (**Table 1**). Labor energy consumption can be determined by multiplying total hours of human activity by the energy coefficients of workers. In Pakistan, where still mechanization of the farms is not so common, there is ample use of human labor in the farm operations. On average 178.45 hours of human labor is used in one hectare of wheat production.

2.1.2 Seed

Seed is mostly provided by seed producers and private seed companies; however, some farmers also use seeds from their farms. Wheat is planted either by seed drill or manually by spreading, the amount of seed also varies according to the sowing method. On average, 134.19 kg/ha wheat seed is used in Pakistan. Energy equivalents of the seed are the energy used in the preparation of wheat seed. Energy inputs of seed can be calculated by multiplying the quantity of seed used per hectare with its energy equivalents (8.65 MJ/kg).

2.1.3 Farm machinery

The embedded energy necessary to manufacture machinery for crop production is a tertiary input that typically has a minor impact on the total energy. [24] reported that machinery accounted for only 1.7% of the total energy associated with corn production. Therefore, energy use in machinery is not included in the estimation of energy used in wheat production.

2.1.4 Fossil fuels

Diesel fuel is the main fuel used in farm machinery and water pump for different crop operations. Consumption of the fuel is dependent on several factors like climate, crop, soil, rolling assistance, and speed. In dry and warm climate use of diesel is more for irrigation than other operations, while in dry farming system diesel is mainly used in tillage and sowing as compared to irrigation. The energy output of diesel fuel was calculated by multiplying liter/ha with fuel equivalent of energy per liter. Energy equivalents of diesel fuel are 44.83 MJ/L. The average diesel fuel use is 39.98 liter/ha in wheat production.

2.1.5 Fertilizer chemical and pesticides

Soil nutrients are the most important obstacle to crop productivity. Fertilizers are used by farmers to increase soil nutrients and resultant growth. Chemical, organic, and biological fertilizers are used in crop production, but just chemical fertilizers are believed to increase the yield more than any other fertilizer. Nitrogen is the main mineral fertilizer being used in crop production. Nitrogen fertilizer is energy-intensive, on the other hand, phosphate and potash do not need high energy. Chemical and chemical fertilizers energy equivalents mean the energy consumption for production, packing, and distribution of the material. On average 177.68 kg per hectare of nitrogen nutrients, 130.17 kg phosphate nutrients, and 37.36 kg potash are used in wheat production in Pakistan. Additionally, 1.60 kg per hectare of herbicides are used in wheat production for weed management.

2.1.6 Water for irrigation

While dry-land wheat is dependent on rains, but irrigated wheat requires irrigation water throughout the production process. On average 8483.07 m^3 of irrigation water is used in one hectare of wheat. The energy equivalents of the water for irrigation input is the indirect energy of irrigation consists of the energy consumed for manufacturing the material for the dams, canals, pipes, pumps, and equipment as well as the energy for constructing the walls and building the on-farm irrigation system. The energy equivalent of the irrigation was estimated to be 0.014 MJ/m^3.

2.2 Energy balances in wheat production

Energy consumption in wheat production includes; labor, embodied energy in seed, chemical and fertilizers, diesel, and water for irrigation. Except water for irrigation all other input energies are same for rainfed (dry land) wheat. There's a wide variation of input energy (**Table 2**), which shows high level of mismanagement in usage of energy resources among some wheat producers. This also indicates that there is great scope for improving energy consumption efficiencies of wheat producers in both farming systems. On average total input energy consumption in irrigated wheat is 49,079.27 MJ ha^{-1} and 31421.59 MJ ha^{-1} for rainfed wheat. The higher use of input energy use in irrigated wheat can be attributed to irrigation energy. Highest share of energy consumption in irrigated wheat is from chemical fertilizer (31.33%), while farmyard manure contributes highest in total input energy consumption in rainfed wheat.

In fertilizers, nitrogen constitutes the highest share, 80.39% and 82.31%, in irrigated and rain-fed wheat, respectively. Highest share of nitrogen in total fertilizer

Energy Inputs	Irrigated		Rain-fed	
	Energy equivalents MJ ha^{-1}	SD*	Energy equivalents MJ ha^{-1}	SD*
Human labor	402.07	166.78	259.45	163.12
Seed	2157.54	193.91	2017.93	157.72
Diesel fuel	9435.13	2697.53	5155.56	1835.76
Water for irrigation	13578.13	7578.43	—	—
Chemicals	627.10	358.56	129.87	324.53
Farmyard manure	7518.00	10767.05	12837.32	12363.56
Nitrogen	13069.26	6998.60	9437.68	6374.82
Phosphate	1702.02	675.63	1474.07	1015.25
Potash	589.68	994.91	109.69	354.96
Yield (output)	50756.79	11715.46	34427.32	20161.36

**Standard Deviation.*

Table 2.
Energy balance in both production systems.

consumption is also recorded in some other countries by [25–27]. Though, nitrogen fertilizer has played key role in enhancing the food production, at the same time excessive use of nitrogen has contributed to soil, water, and air pollution in many parts of the world. Sustainability of crop production is threatened by overuse of inorganic fertilizer which inflicts severely on soil health. The need for nitrogen can be reduced by fertilization management and integrating a legume in crop rotation. In order to reduce demand for inorganic fertilizer in medium term, soil fertility and organic matter contents can be increased by applying composts, chopped residues or other soil amendments. Almost, 55% of the farmers in Punjab (Pakistan) just use inorganic fertilizers, and 30% use combination of both organic and inorganic. Furthermore, farmers use more than recommended dose of fertilizer (Zulfiqar et al. 2017). So, adopting balanced use of fertilizer by wheat producers will reduce the use of nitrogen, as nitrogen has been found to be main difference between conventional and sustainable farming system (Pimentel et al. 2005). So, consumption of nitrogen with organic fertilizer and balanced use of fertilizer will reduce energy consumption in production system and improve its productivity.

Water for irrigation is the second largest consumer of energy in irrigated wheat. Diesel fuel is used for operating machinery in wheat production, it constitutes 19.25% of the total input energy consumption in irrigated and 16.4% in rain-fed. [28] found diesel as the main energy input after fertilizer in wheat, sugar beet, canola and maize. Particularly in irrigated land where diesel is also used for ground water pumping its use is higher (9435.13 MJ ha^{-1}) than rain-fed (1835.76 MJ ha^{-1}). [29] reported that ground water pumping consumes 61% of direct energy in Punjab. Pumping systems are mostly dependent on fossil fuels, almost 91% of the total installed pumps use diesel driven motors.

Furthermore, share of human labor (0.81%) with amount of 402.07 MJ ha-1 in the irrigated farming system is the least in total energy consumption, followed by chemicals and seed. In rain-fed wheat share of chemical (0.4%) in total energy consumption was negligible followed by human labor and seed. The average output energy in irrigated wheat was calculated as 50756.79 MJ ha-1, and 34427.32 MJ ha-1 for rain-fed wheat farming.

2.3 Energy indices

Energy ratio which is a relationship between input and output energy is often used as an index to measure energy efficiency in crop production. Energy ratio can also be used to determine subsistence of the system in isolated societies. If ratio is lower than one, it means system is losing energy and if it is higher than one it means system is earning energy. Energy efficiency for irrigated and rain-fed wheat production is estimated to be 1.03 and 1.09, respectively (**Table 3**). Irrigation can be the reason for difference between two production system, higher energy efficiency for rain-fed and comparatively low for irrigated. This suggests that an efficient irrigation system will improve energy ratio in irrigated wheat. For comparisons between two production system energy efficiency may not be very good approach, because difference in energy efficiency can be due to difference in energy input and yield. [30] said that energy productivity is comparatively a better parameter to show the difference between two production systems, as it calculates the ratio of production yield per kg into consumer energy. Estimates of energy productivity shows that, for each unit of input energy (MJ) consumed in wheat, 0.07 and 0.06 yield units are achieved in rain-fed and irrigated wheat production, respectively (**Table 3**). This again shows that, energy is more efficiently being used in rainfed production system. Specific energy was estimated to be 12.70 and 14.49 MJ kg^{-1} for rain-fed and irrigated wheat production (**Table 3**]. Lower value of specific energy shows that less amount of energy is used for production of one yield unit, as it is reciprocation of energy productivity. As a result, rain-fed is superior to irrigated wheat production from specific energy perspective also. The net energy per hectare for rain-fed and irrigated wheat production was 3005.73 and 1677.52 MJ, respectively.

The distribution of input energy according to renewable and non-renewable, direct and indirect forms is important for energy analysis. In both production systems, ratios of indirect and non-renewable energy are higher than direct and renewable energy. Higher share of non-renewable energy in irrigated wheat production is due to high dependence on fossil fuels. In other words, common use of diesel driven motor for ground water pumping and higher use of chemical fertilizer is the reason for share of

Energy indices	Unit	Rainfed	Irrigated	Explanation of parameters
Energy use efficiency (Ee)	—	1.09	1.03	=Output energy/total input energy
Energy Productivity (E_p)	Kg MJ^{-1}	0.07	0.06	=Yield (kg)/ total input energy
Specific energy (S_e)	MJ kg^{-1}	12.70	14.49	=Total input energy/yield(kg)
Net energy (N_e)	MJ ha^{-1}	3005.73	1677.52	= Output energy-Total input energy
Direct energy (DE)	MJ ha^{-1}	5415.01	23415.33	=Human labor + water for irrigation + Diesel fuel
Indirect energy (IDE)	MJ ha^{-1}	26006.56	25663.6	=Tractor + Harvester + Herbicides + Seed + Chemical fertilizers + Farmyard manure
Renewable energy (RE)	MJ ha^{-1}	15114.7	23665.75	=Human Labor + Seed +Water for irrigation + Farmyard manure
Non-renewable energy (NRE)	MJ ha^{-1}	16306.67	25423.19	=Tractor + Harvester +Diesel Fuel + Herbicides + Chemical fertilizers
Total energy input	MJ ha^{-1}	31421.59	49079.27	=NRE + RE or = DE + IDE

Table 3.
Energy indices for wheat production in Pakistan.

non-renewable energy. Penetration of electricity driven irrigation systems, efficient water management, and balanced use of fertilizer will reduce share of the non-renewable energy in agricultural systems. Moreover, investment in renewable energy system such as solar, wind etc. will improve the situation. According to [31] improvement in energy efficiency and increase in amount of renewable energy in agricultural system is very important to achieve sustainable system of food production.

3. Efficiency analysis

Traditionally input–output ratios have been used to determine efficiency. Though, input–output ratios are also helpful in explaining efficiency of the system. However recently, researchers have started applying Data Envelopment Analysis (DEA) to analyze efficiency of farmers. DEA is generalization of single-input single-output technical efficiency measure of Farrel (1957) and use multiple-input multiple-output technique to evaluate the relative efficiency of peer units with respect to multiple performance measures [32, 33]. A decision-making unit called DMU are under evaluation in DEA. A DMU is considered as efficient when no other DMU can produce more output using an equal or lesser amount of inputs [34].

3.1 Efficiency estimates

An input-oriented DEA approach was used to determine technical, pure technical and scale efficiencies of wheat farmers in both production systems. Technical efficiency of all farmers was evaluated using CCR model, and BCC model was used to determine pure technical (PTE) and scale efficiency (SE). The results from CCR and BCC model for rain-fed wheat producers in Pakistan are presented in **Figure 2**. It can be seen from the figure that only about 18% rainfed farmers are technically efficient. This shows that there is a considerable inefficiency between

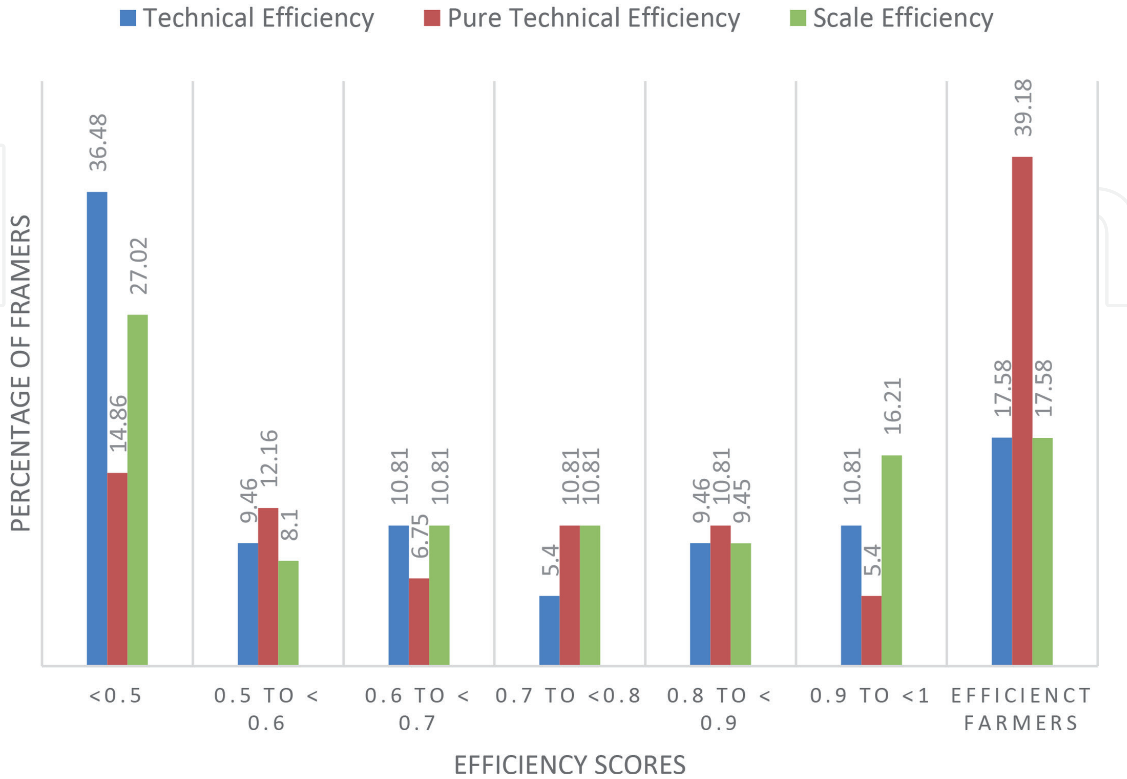

Figure 2.
Percentage distribution of TE, PTE, and SE scores of wheat producers in rainfed production system.

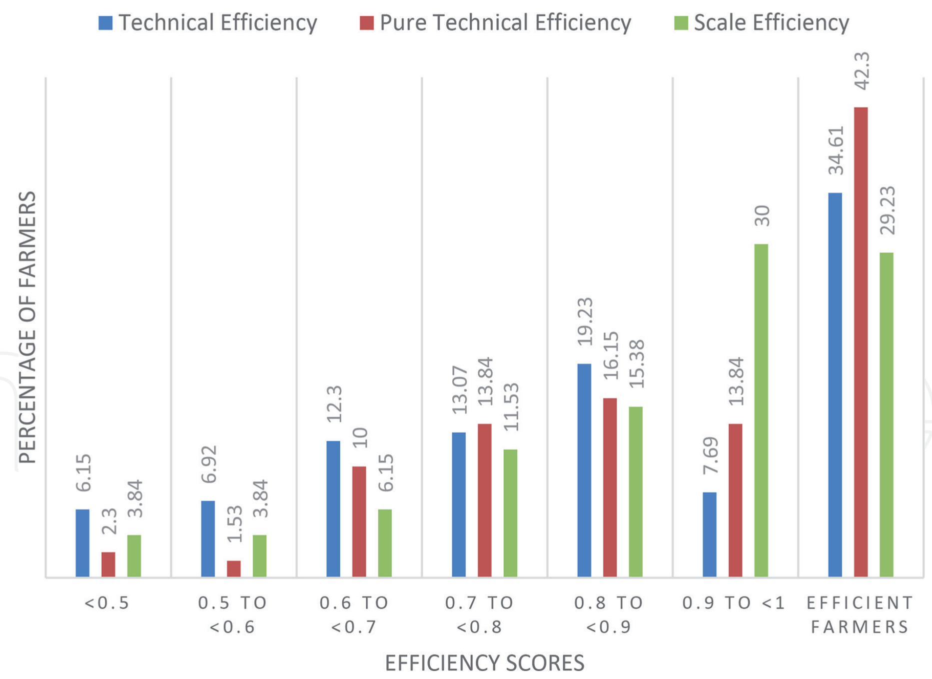

Figure 3.
Percentage distribution of TE, PTE, and SE scores of wheat producers in irrigated production system.

wheat producers in the study area. From efficient farmers 17% are efficient in both technical and pure technical efficiency score; this means that these farmers are globally efficient and operating at most productive scale size, on the other hand the 22% farmers are only locally efficient farmers and they have disadvantageous scale size. Additionally, 14% and 36% of the farmers have pure technical and technical efficiency score less than 0.5.

Efficiency scores of irrigated wheat producers are demonstrated in **Figure 3**. About 34% irrigated farmers are technically efficient and 42% are pure technically efficient. Among efficient farmers 90% are globally efficient and 10% are locally efficient due to scale problem. Considering CCR model 7% farmers have efficiency scores between 0.9 to less than 1 and 19% have between 0.8 to less than 0.9. On the other hand, in BCC model 13% had scores between 0 to less than 1 and 16% had between 0.8 to less than 0.9. Less than one score of the pure technical efficiency means that producer is using more energy from different sources than required [35].

Table 4 presents the summarized statistics for technical efficiency, pure technical efficiency and scale efficiency for wheat producer of Pakistan. The results revealed that average technical efficiency of wheat producer in rain-fed production system was 0.62 and in irrigated it was 0.82. The pure technical efficiency and scale efficiency was 0.78 and 0.67, respectively in rain-fed, and 0.87 and 0.85 in irrigated wheat production system. The technical efficiency of irrigated wheat farmers varied

Particular	Rain-fed				Irrigated			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Technical Efficiency	0.629	0.291	0.126	1	0.825	0.179	0.224	1
Pure Technical Efficiency	0.782	0.222	0.35	1	0.879	0.141	0.420	1
Scale Efficiency	0.674	0.287	0.12	1	0.869	0.161	0.230	1

Table 4.
Average efficiency of rain-fed and irrigated wheat production in Pakistan.

Inputs/output (unit)	Rainfed			Irrigated		
	10 EF (1)	10 IF (2)	Difference (%) (2–1) *100/2	10 EF (1)	10 IF (2)	Difference (%) (2–1)*100/2
A. Inputs						
Human Labor (h)	80.04	110.84	27.78	184.65	257.92	28.40
Seed (kg)	133.38	136	1.92	135.88	130.91	−3.79
Diesel (l)	89.16	65.94	−35.21	140.58	159.06	11.61
Farmyard manure (kg)	25,688	49,894	48.51	0	39,520	
Herbicide (kg)	0.12	0	−0.12	1.70	2.59	34.36
Nitrogen (kg)	102.91	98.84	−4.11	148.2	259.35	42.85
Phosphate (kg)	80.27	86.45	7.14	104.97	160.55	34.61
Potash (kg)	12.33	0	−12.33	49.35	123.31	59.97
Water for irrigation	—	—	—	2187.43	3033.06	27.88
B. Output						
Wheat (kg)	4004.64	592.92	−575.40	3946.32	2041.20	−93.33

**EF = Efficient Farmers.*
**IF = Inefficient Farmers.*

Table 5.
Amount of input and output for 10 efficient and inefficient wheat producers.

between 0.12 to 1 which shows that all farmers did not have knowledge of right production techniques or they were not applying at the right time. The low average values of scale efficiency in both production systems imply that the average size of the wheat farms is not equal to optimal farm size. This mean if the inefficient wheat farmers operate at optimal scale size considerable saving of energy from different sources is possible without affecting the yield level.

3.2 Input use pattern of efficient and inefficient wheat producers

The amount of physical inputs and output for 10 efficient and inefficient farmers based on CCR model in both rain-fed and irrigated wheat production system are presented in **Table 5**. The efficient farmers use all inputs in less amount compared to inefficient farmers in irrigated production system. While in rain-fed production system except diesel and nitrogen use of all other inputs was low for efficient farmers than inefficient. Inefficient farmers in rain-fed production system use more human labor hours by 27.78%, seed by 1.92%, FYM by 48.5%, and phosphate by 7.14%. In irrigated production system, use of inputs by efficient farmers is lower than inefficient farmers by, 28.40% for human labor hour, 11.61% for diesel fuel, 34% for chemicals, 42.85% for nitrogen, 34.6% for phosphate, 59.97% for potash and 60% for water for irrigation. Looking at output it is evident that yield of efficient farmers is higher than inefficient farmers in both production systems.

4. Conclusions

Energy security and environmental problems due to its use are the major concern for most of the developing world. Agriculture is among the largest energy consuming sectors; this chapter was an effort to estimate energy use in wheat production which is an important staple food in Pakistan. Data on quantity of different energy inputs used in wheat production was collected through field surveys. Energy consumption in wheat was calculated by multiplying amount of inputs with their energy equivalents drawn from literature. Energy indices which are important to interpret how energy is being used were also estimated. A non-parametric data envelopment analysis technique was used to identify efficient and inefficient farmers.

In Pakistan two different wheat production systems prevail (rain-fed and irrigated). So, all estimations were performed separately for both production systems. The results of the study showed that, FYM, fertilizer, and diesel fuel has the highest share in total input energy consumption in rain-fed wheat, while in irrigated wheat fertilizer, water for irrigation, and diesel were the main energy consuming inputs. In both production systems consumption of indirect and non-renewable energy resources was higher than direct and renewable energy resources. The results of the DEA analysis revealed that, 85% of the farmers in rain-fed wheat production and 65% in irrigated wheat production were technical efficient in Pakistan. Based on BCC model the estimate of target energy use showed that there is a great scope for energy savings from various input sources. If the optimum energy requirement levels are adopted by farmers, then it would lead to increase in energy efficiency. Comparison of 10 most efficient and no-efficient farmers revealed that input usage of inefficient farmers is comparatively higher than efficient ones with no difference in yield output and size. Based on result it could be said that there is dire need for dissemination of information about best agricultural practices and economic benefits of use of inputs at recommended levels. Adoption of better agriculture technologies is highly recommended as it will result in improvement in efficiency of use of diesel and human labor. Most of the wheat is cultivated manually and majority of the farmers apply flood irrigation leading to higher use of water and diesel fuel also. Efficient management of water for irrigation would improve energy efficiency and minimize environmental impacts.

Conflict of interest

The authors declare no conflict of interest.

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References

[1] Yuan S, Peng S, Wang B, Man J. Evaluation of the energy budget and energy use efficiency in wheat production under various crop management practices in China. Energy 160 (2018) 184-191. 10.1016/j.energy.2018.07.006.

[2] Evenson RE, Gollin D. Assessing the impact of the green revolution, 1960 to 2000. Science 2003; 300:758-62.

[3] Kazemi H, Kamkar B, Lakzaei S, Badsar M, Shahbyki M. Energy flow analysis for rice production in different geographical regions of Iran. Energy 2015;84: 390-6.

[4] Maraseni T, Chen G, Banhazi T, Bundschuh J, Yusuf T. An assessment of direct on-farm energy use for high value grain crops grown under different farming practices in Australia. Energies 2015; 8:13033-46.

[5] Dash PK, Bhattacharyya P, Shahid M, Roy KS, Swain CK, Tripathi R, Nayak AK. Low carbon resource conservation techniques for energy savings, carbon gain and lowering GHGs emission in lowland transplanted rice. Soil Res 2017; 174:45-57.

[6] Jonge AM. Eco-efficiency improvement of a crop protection product: the perspective of the crop protection industry. Crop Protect 2004; 23:1177-86.

[7] Ghorbani R, Mondani F, Amirmoradi S, Feizi H, Khorramdel S, Teimouri M, Sanjani S, Anvarkhah S, Aghel H. A case study of energy use and economical analysis of irrigated and dryland wheat production systems. Appl Energy 2011; 88:283-8.

[8] Lal R. Carbon emission from farm operations. Environ Int 2004; 30(7):981-90.

[9] Sykes AS, Topp CFE, Rees RM. Modelling nutrient cycles in agriculture and their environmental impacts. In: Assessing the environmental impact of agriculture. Burleigh Dodds Science Publishing Limited: Series in Agricultural Science; 2019.

[10] Garnett T. Where are the best opportunities for reducing greenhouse gas emissions in the food system (including the food chain)? Food Policy, 2011; 36: S23-32.https://www.sciencedirect.com/science/article/abs/pii/ S0306919210001132.

[11] Hoffman E, Cavigelli MA, Camargo G, Ryan M, Ackroyd VJ, Richard TL, Mirsky S. Energy use and greenhouse gas emissions in organic and conventional grain crop production: Accounting for nutrient inflows. Agric Syst, 2018;162:89-96. https://www.sciencedirect.com/science/article/abs/pii/S0308521X 16305923.

[12] ˇSarauskis E, Buragien˙e S, Masilionyt˙e L, Romaneckas K, Aviˇzienyt'e D, Sakalauskas A. Energy balance, costs and CO2 analysis of tillage technologies in maize cultivation. Energy 2014; 69:227-35. https://www.sciencedirect.com/science/article/abs/pii/S0360544214002370.

[13] IPCC. Climate change 2007: impacts, adaptation and vulnerability. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE, editors. Contribution of Working Group II to the fourth assessment report of the intergovernmental panel on climate change. Cambridge, UK: Cambridge University Press; 2007. p. 976.

[14] Khoshnevisan B, Rafiee S, Omid M, Yousefi M, Movahedi M. 2013. Modeling of energy consumption and GHG (greenhouse gas) emissions in wheat production in Esfahan province of Iran using artificial neural networks. Energy. 52:333-338.

[15] Vlek PLG., Rodríguez-Kuhl G., Sommer R. Energy use and CO2 production in tropical agriculture and means and strategies for reduction or mitigation. Environ Dev Sustain, 6:213-33, 2004.

[16] Kroeze C., Mosier A., Bouwman L. Closing the global N2O budget: a retrospective analysis 1500-1994.Global Bio geochem Cycl, 13:1-8, 1999.

[17] Khan S, Khan M, Hanjra M, Mu J. 2009. Pathways to reduce the environmental footprints of water and energy inputs in food production. Food Policy. 34:141-149.

[18] Uhlin H. Why energy productivity is increasing: an I-O analysis of Swedish agriculture. Agric Syst, 56 (4):443-65, 1998.

[19] Streimikiene D., Klevas V., Bubeliene J. Use of EU structural funds for sustainable energy evelopment in new EU member states. Renew Sustain Energy Rev 2007;116:1167-87.

[20] Braun H-J, Atlin G, Payne T. Multi-location testing as a tool to identify plant response to global climate change. In: Reynolds MP, editor. Climate change and crop production. CABI International; 2010. p. 115-38.

[21] Stout BA. Handbook of energy for world agriculture. London, New York: Elsevier Applied Science, Sole distributor in the USA and Canada, Elsevier Science Pub. Co. 1990.

[22] Wallgren C., Höjer M. Eating energy–Identifying possibilities for reduced energy use in the future food supply system. Energy Policy, 37(12):5803-13, 2009.

[23] Pimentel D., Hepperly P., Seidel R., Hanson J., Douds D. Environmental, energetic, and economic comparisons of organic and conventional farming systems. Bioscience, 55(7):573, 2005.

[24] Farrell A.E., Plevin R.J., Turner B.T., Jones A.D., O'Hare M., Kammen D.M. Ethanol can contribute to energy and environmental goals. Science. 311: 506-508, 2006.

[25] Mousavi-Avval SH, Rafiee S, Jafari A, Mohammadi A. 2011. Energy flow modeling and sensitivity analysis of inputs for canola production in Iran. Journal of Cleaner Production. 19:1464-1470.

[26] Mobtaker HG, Keyhani A, Mohammadi A, Rafiee S, Akram A. 2010. Sensitivity analysis of energy inputs for barley production in Hamedan Province of Iran. Agriculture, Ecosystems & Environment. 137:367-372.

[27] Khoshnevisan B, Rafiee S, Omid M, Mousazadeh H. 2013. Applying data envelopment analysis approach to improve energy efficiency and reduce GHG (greenhouse gas) emission of wheat production. Energy. 58:588-593.

[28] Börjesson P, Tufvesson LM. 2011. Agricultural crop-based biofuels – resource efficiency and environmental performance including direct land use changes. Journal of Cleaner Production. 19:108-120

[29] Siddiqi A, Wescoat JL. 2013. Energy use in large-scale irrigated agriculture in the Punjab province of Pakistan. Water International. 38:571-586.

[30] Ziaei S, Mazloumzadeh S, Jabbary M. 2015. A comparison of energy use and productivity of wheat and barley (case study). Journal of the Saudi Society of Agricultural Sciences. 14:19-25

[31] Moore SR. 2010. Energy efficiency in small-scale biointensive organic onion production in Pennsylvania, USA. Renewable Agriculture and Food Systems. 25:181-188.

[32] Charnes A. 1994. "Data envelopment analysis: theory, methodology, and application".

[33] Cooper WW, Seiford LM, Tone K. 1999. Data envelopment analysis: a comprehensive text with models, applications, references, and DEA-Solver software. [place unknown]: Kluwer Academic.

[34] Khalili-Damghani K, Tavana M, Santos-Arteaga FJ, Mohtasham S. 2015. A dynamic multi-stage data envelopment analysis model with application to energy consumption in the cotton industry. Energy Economics. 51:320-328.

[35] Chauhan NS, Mohapatra PK, Pandey KP. 2006. Improving energy productivity in paddy production through benchmarking—An application of data envelopment analysis. Energy Conversion and Management. 47:1063-1085.